Lakehead University

Knowledge Commons,http://knowledgecommons.lakeheadu.ca

Electronic Theses and Dissertations | Undergraduate theses

2020

An Ontario approach to urban pest management: a case study for emerald ash borer

Thordarson, James

AN ONTARIO APPROACH TO URBAN PEST MANAGEMENT:

A CASE STUDY FOR EMERALD ASH BORER

by

James Thordarson

Source: https://arnprior.ca/live/eab/

FACULTY OF NATURAL RESOURCES MANAGEMENT
LAKEHEAD UNIVERSITY
THUNDER BAY, ONTARIO

AN ONTARIO APPROACH TO URBAN PEST MANAGEMENT:

A CASE STUDY FOR EMERALD ASH BORER

by

James Thordarson

An undergraduate thesis submitted in partial fulfillment of the requirements for the degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management
Lakehead University
Thunder Bay, Ontario

April 2020

LIBRARY RIGHTS STATEMENT

Signature: ________________________________

Date: ___April 9, 2020________________________

A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty or Lakehead University.

ABSTRACT

The Emerald Ash Borer (EAB) is an invasive insect pest that was imported to North America from Asia in packaging materials and shipping containers. It first became established in Detroit, Michigan and Windsor, Ontario in 2002. It quickly spread through Southern Ontario, decimating urban and natural ash populations. There are currently several options to control the outbreak of this pest as it continues to cause ecological and economic detriment. These measures include, but are not limited to, complete tree removal, or the injection of insecticides into the tree. Thus far, Thunder Bay, Ontario has done an excellent job protecting and mitigating both the overall effects and the spread of EAB to other areas of Canada. Climate change is an ever-encroaching possibility that creates larger problems for mitigation of beetle populations.

Key words: Emerald Ash Borer, Invasive, Ecological and Economic, Treatment options, Thunder Bay

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to thank Dr. Henne, my supervisor, for the opportunity to complete this research and present this topic. I would also like to thank Vince Rutter and Tim Nosworthy of Rutter Urban Forestry for providing work experience that got me interested in Emerald Ash Borer and Vince for being my second reader. Acknowledgment must also be given to Dr's Meyer and Leitch for their help and guidance throughout this process. Data was provided by the City of Thunder Bay thanks to Robert Scott, the City of Toronto, the City of Windsor and City of Winnipeg. Acknowledgment should also go out to Mr. Clark Christensen from the City of Duluth for providing information about the how Northern States are combating the beetle.

INTRODUCTION

This thesis was written on the premise that Thunder Bay requires an adjustment to its Integrated Pest Management (IPM) plan. The main topic is the control measures in place for the invasive *Agrilus planipennis*, commonly known as the Emerald Ash Borer – from here on referred to as EAB. The effects of climate on reoccurring populations and the different life history of the beetle as a result of colder annual temperatures will be examined. This is an important subject to me as it was part of my summer job to provide EAB treatment to privately owned ash trees in Thunder Bay. We must understand the best way to approach insect outbreaks in an urban setting because they may become more and more common in the future. Only in recent years has Thunder Bay shifted to a less tree species monoculture city plan and, as a result, the previous urban tree species consisted of mainly ash and prior to that it was American elm.

Unfortunately, using both of these tree species is no longer possible because of poor pest management practices. The city of Thunder Bay is also having problems with the native *Agrilus anxius*, commonly known as the Bronze Birch Borer (BBB). This BBB is in the same genus as EAB and also follows a similar life history and method of attacking birch trees. The City of Thunder Bay does not have protocols in place for controlling native beetles that only attack stressed and less vigorous trees. Their only plan to combat either of these pests is insecticide for EAB and tree removal for both.

Currently, the City of Thunder Bay also does not allow the planting of either *Fraxinus spp.* or *Betula spp.* within the city. Furthermore, climate change is creating enormous problems for Canada, primarily an environment in which beetle populations are more devastating than ever. The mountain pine beetle outbreak in British Columbia is a prominent example of this phenomena. A higher mean temperature during the winter months has created an environment in which the beetle population can persist at epidemic levels. As a result, this tiny beetle has decimated pine forests in Alberta and British Columbia.

Presently, in areas like Thunder Bay and northern states such as Minnesota, it is estimated that up to 90% of the EAB population can be killed during extreme cold snaps. However, rising temperatures may give way to reduced beetle mortality. How will a city like Thunder Bay, a typical municipality with a lower budget, deal with increases in the EAB population, and how can we better understand how to prevent potential outbreaks of other urban tree pests? Current methods for urban tree pests such as EAB include, but are not limited to, the use of TreeAzin, a neem kernel extract that is injected into ash trees and kills the EAB larvae. The other option for treatment is tree removal and disposal of the wood. Removals can be a costly endeavor and both treatments only cover trees on city property.

OBJECTIVE

To determine the current effectiveness of our (Thunder Bay's) IPM program, data collected from the city were compared to that of some southern Ontario cities as well as Duluth, a northern US city in the state of Minnesota. City data was used to determine where outbreaks started and how quickly it spread, current population estimates, and how the divide between city-owned and privately-owned trees has affected treatment plans. Discussions of current IPM plans were held with the current Thunder Bay city forester and the previous city forester to reach a conclusion of what can realistically be done. The literature review consisted of mainly EAB-related articles and the effects of climate and IPM plans across North America. The objective of this paper is to determine the effectiveness of the current IPM plan in Thunder Bay and if (or how) it can be modified to better protect the city against future outbreaks of insects. My current null hypothesis is that the City of Thunder Bay is currently performing at a level that will maintain EAB populations below epidemic levels. The intent of this thesis is to be a useful contribution to city planning when dealing with pests and how it can be cost effective.

LITERATURE REVIEW

LIFE HISTORY AND BIOLOGY OF EAB

Agrilus planipennis, commonly known as the Emerald Ash Borer (hereafter EAB) is a member of the family Buprestidae, of the order Coleoptera (Ryall 2017). A species native to Asia, it was positively identified in 2002 by Dr. Eduard Jendek in Detroit Michigan (Poland 2006). Later that year it was found in Windsor, Ontario, just across the border from Detroit. It is a very distinguishable iridescent green colour and adults typically measure 7-8 mm in length (de Groot et al. 2006). Figure 1 shows an average adult EAB. An adult can live for 3-6 weeks and females will lay anywhere from 40-90 eggs on average, with long-lived females laying upwards of 200 eggs (Herms 2014, Poland 2006). Eggs are approximately 1 mm in diameter and are laid underneath the bark of ash trees; the larvae then hatch under the bark and begin to tunnel while feeding and growing (Bauer et al. 2003). In Bauer et al. (2003) it is also stated that there are four distinct larval stages before pupation occurs. This beetle has either a one- or two-year life cycle that is dependent upon temperature (Herms et al. 2014). A more northern population, such as those found in Thunder Bay, would typically have a two-year life cycle, with overwintering occurring in the larval form and not the prepupal form in warmer regions; development and pupation will occur in the following summer (Bauer et al. 2003, DeSantis et al. 2013). Larval galleries are created under the bark within the phloem to sustain the growth of the insect (McKenney et al. 2012). The galleries are serpentine in shape and easily distinguishable. Once the larva has pupated and the adult emerges, they spend approximately one week feeding on ash leaves before reaching sexual maturity (Bauer et al. 2003, Herms 2014). Emerging adults are immediately capable of sustained flight and have the ability to mate. An adult will continue to breed during the remainder of their 3-6 week life span (Bauer et al. 2003, Lyons et al. 2004).

Similar to its cousin the bronze birch borer, *Agrilus anxius*, another buprestid beetle, EAB is very host specific and only feeds and lays eggs in species of the genus *Fraxinus*. *Fraxinus* are the true ash and EAB does not feed on mountain ash, the genus *Sorbus.* No North American ash species have any resistance to EAB, other than the blue ash, *F. quadrangulate*, a Carolinian species. Chinese ash species, however, do show resistance to EAB (Herms 2014, McKenney et al. 2012). This resistance is mainly attributed to coevolution. Some of the only recordings of high EAB populations in China were within plantations of North American ash species used for reforestation (Liu et el. 2003, Bauer et al 2003, Gould et al. 2005). According to Herms and McCollough (2014) EAB is different from almost all other buprestids in one major way; they are able to attack and overcome healthy trees. This makes them especially deadly to ash populations compared to other borer beetle species.

Figure 1. Adult beetle. *Agrilus planipennis*.

Source: Iowa State University

IMPACT OF THE BEETLE

EAB is a detriment to both urban and natural ash forests. When Dutch Elm Disease swept through the North American continent and devastated the American Elm (*Ulmus Americana*), city officials across the majority of North America determined that the most suitable tree species to use as a replacement were those of the genus *Fraxinus* (McKenzie 2010). The most common of these are green ash (*F. pennsylvannica*) as well as white ash (*F. Americana*) and black ash (*F. nigra*).

In general, ash is an extremely hardy tree. They are capable of growing under poor conditions and are even able to tolerate the high salt loads found on our northern streets during the winter months. As a commercial species, ash is typically used as tool handles and furniture making; and makes up 7.5% of the volume of US hardwood saw timber (Federal Register 2003). Unfortunately for ash, this creation of high concentration ash tree monoculture was once again the instigating force behind its population extirpation.

It is expected that, given enough time, 100% of native ash trees will be eliminated from their natural range in North America (DeSantis 2013). Decisions to protect tree assets can be complex, involving relatively straightforward financial considerations such as treatment, removal, and replacement costs; as well as more subtle factors, like the influence of tree cover on property values, home energy budgets, and even what economists may term as "existence" values (Krutilla 1967; Boardman et al. 2001). The impacts of EAB come in two forms, ecological and economic.

Ecological Impacts

The ash, although very hardy and capable of growing in harsh climates and under poor conditions are no match for vascular disruption. Phloem is a means of transport for nutrients through the tree and into the crown (Toronto's Forest Threats 2016). EAB larvae feed on these tissues. The estimated loss of ash trees in North America is in the billions and is unlikely to slow without proper intervention and regeneration programs (Klooster et al. 2012). It has been determined that an estimated 30% of ash trees are killed each year following EAB establishment, with a large ash tree taking anywhere from 3-5 years to succumb and small trees can be killed in only one year (McKenney et al. 2012, Poland 2006). These dead and dying trees are a hazard on roadways, in urban areas, and in natural forests, and they would be considerably more prone to windthrow. Dr. Leonard Hutchison a mycologist and professor at Lakehead University states that a stressed tree is significantly more vulnerable to disease. The loss of an entire species of tree can be devastating to forest biodiversity and forest structure. In cities, street trees provide shade, wind breaks, and can even help to mitigate storm water.

Figure 2. Crown thinning from EAB.

Source: Iowa State University

Economic Impacts

In general, there are four economic costs associated with EAB; removal, replacement, treatment and community overhead costs (McKenney et al 2012, Ash line the streets of many major cities in Canada and the USA. A recent tree inventory done by the City of Winnipeg showed the total ash tree population within the city to be approximately 280,000, with over 100,000 trees lining boulevards. There are another 260,000 trees on private land and in other natural spaces. Dr. Hutchison, a native of Winnipeg, stated that the rest of the city is still primarily American elm, with a population of 112,000 elm trees as well. That means approximately 75-80% of trees on the streets of Winnipeg are at risk of dying. These numbers were taken after 72,100 ash were already removed. In 2012 it was estimated that the total Canadian inventory of street ash was upwards of 1.2 million trees, with a treatment plan cost totaling a massive 1,177 million dollars (McKenney 2012). McKenney (2012) also stated there was a potential cost of 10.7 billion dollars for the Northeastern United states over the next ten years to be spent on treatment programs, removals and replacement trees. Figure 3 shows a simulated model for the economic impacts of EAB. The model predicts cumulative impacts over the course of 30 years starting at year zero of the infestation. The model has three different figures showing projected economic spending in billions of dollars for three scenarios: a slow spread and 0% of ash treated, a medium spread with 10% of ash treated and a fast spread with 50% of ash treated. The cost and impact go up with each scenario as a faster spread means more infected trees and thus creating more trees to be treated. Toronto alone has a structural value placed on their ash trees at $570 million for 860,000 trees (Toronto's Forest Threats 2016). Poland and McCollough (2006) state that in 2004 more than $850,000 in grants was provided to municipalities in Michigan for the planting of nonhost trees to EAB.

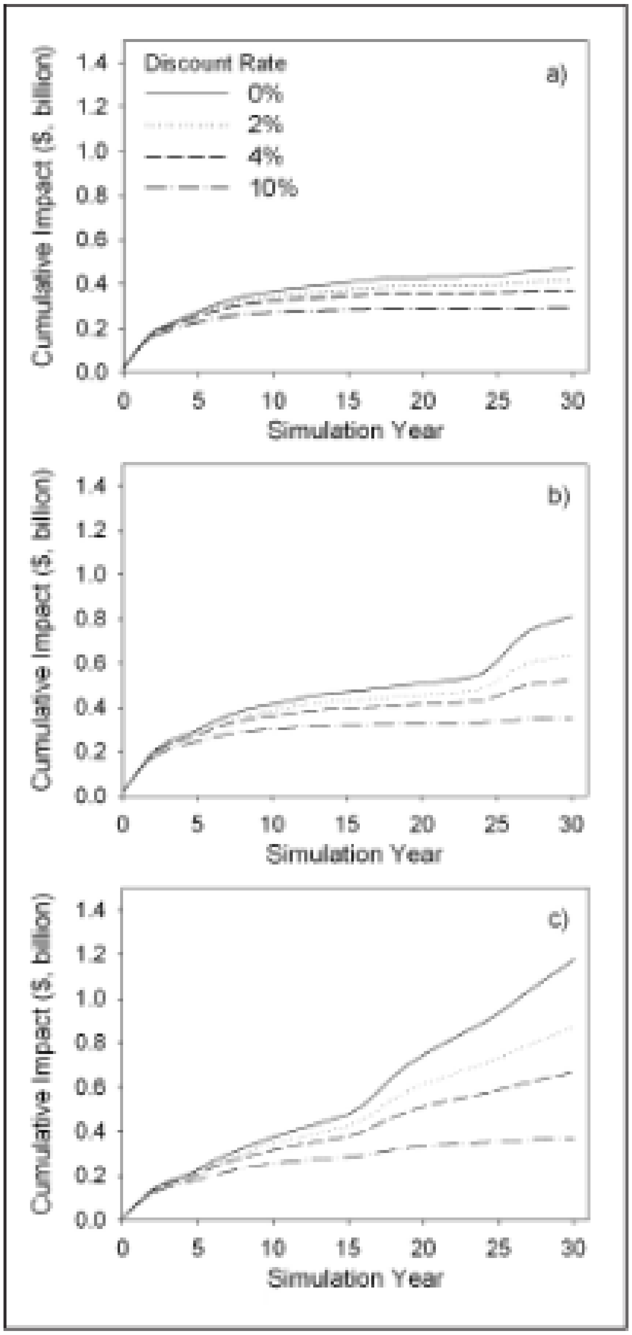

Figure 3. Simulation of expected economic impact based on three scenarios: a) slow spread and 0% of ash treated, b) medium spread and 10% of ash treated and c) fast spread and 50% of ash treated.

Source: McKenney 2012

The rate of spread of EAB is manageable if we consider the daily flight distance of the average beetle to be around 40-80 m (Tussey et al. 2018). This flight distance is based on laboratory data and does not take into account the need to mate and feed in the area of emergence where food is likely to be found. Regrettably, the movement of EAB-infested firewood through the country has multiplied the rate of spread by an incredible amount. The hitchhiking of larvae under the bark of firewood is the main method of transportation. A beetle can move hundreds of kilometers in a day by utilizing this method. The impact of EAB will be felt differently across the continent because of several factors; abundance of ash, treatment plans and mortality of the beetle from external factors. One of the most important external factors for mortality of the beetles is temperature, especially in a northern city like Thunder Bay.

COLD HARDINESS AND SURVIVAL

The EAB is a freeze tolerant species that is capable of supercooling its own body through production of glycerol to survive very cold temperatures (Herms 2014, Tussey et al. 2018). The supercooling ability has a recorded low of -35.3_{o} C (DeSantis et al. 2013). Other studies have stated that the average low temperature the emerald ash borer can withstand is only around -25_{o}C (Venette and Abrahamson 2010). These difference in supercooling temperatures are likely inherited and developed over several generations based on latitudinal occupancy of the population. However, the subzero temperatures required to induce EAB mortality are not simply the ambient temperature. In an unpublished study by Therese Poland the average depth of overwintering occurs 1.5 cm under the bark and at a height just above root collars. These two factors alone mean that insulating effects of both snow cover and the bark must be taken into consideration for temperature related mortality.

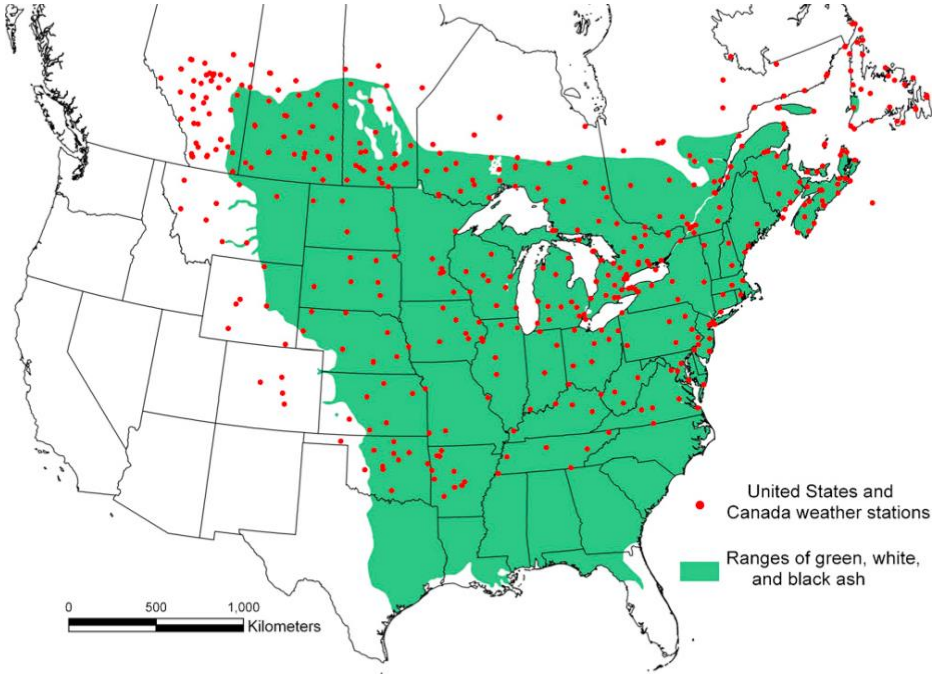

Figure 4. Range of ash in North America

Source: DeSantis et al. 2013

As a northern City, Thunder Bay has been able to rely on low winter temperatures and polar vortexes to manage EAB and keep it at endemic levels. However, it is also possible that some previously unconsidered factors, such as urban heating or climate change, may allow EAB to persist in cold urban centers for periods of years (Cuddington et al. 2018). A sunny day can considerably warm the trunk of a tree providing relief for the beetle larva (Venette and Abrahamson 2010). Incidentally, this warming effect is somewhat of a double-edged knife. If this heating and cooling takes place more frequently, the winter acclimation of the beetle can be disrupted (Herms 2014 and DeSantis et al. 2013). A temperature increase to above 5 degrees Celsius and then back down to minus 25 degrees Celsius can severely disrupt the supercooling and results in much higher mortality. DeSantis (2013) goes on to state that no evidence exists that prolonged exposure to extreme low temperatures increases mortality. The temperature must reach a point below the beetle's ability to supercool and temperature fluctuations could be a saving grace for northern populations of ash. Figure 5 shows the average temperatures for two western cities, with predicted and observed temperatures with the mortality rates of the beetle. Edmonton and Regina both experience subzero temperatures during winter months but neither city achieved temperatures equal to the predicted that would be necessary to kill 99% or beetles and very rarely reached the 75% mortality temperatures. This means that a large enough portion of a population of EAB would be able survive the winter months and persist with an infestation.

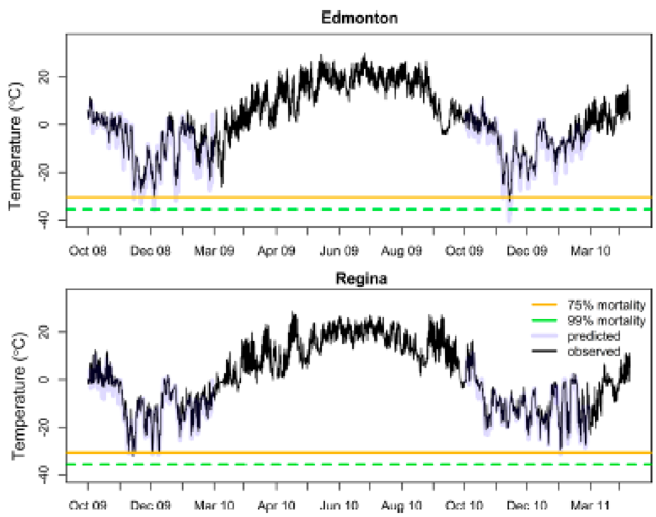

Figure 5. Temperature and mortality percentage for EAB.

Source: Cuddington et al. 2018.

The ability of EAB to survive extreme cold is a major factor in its persistence in northern regions. The overwintering temperatures did not affect or dictate the energy reserves and flight capacity of EAB (Tussey et al. 2018). Tussey explains that although low temperatures do affect the overall population mortality, those that did emerge were still healthy, vigorous and capable of immediate flight. More research is needed regarding flight capacity following extreme low temperatures.

Research by Cuddington et al. (2018) suggests that northern populations of ash may experience frequent enough extreme cold events to prevent complete collapse from EAB. Essentially, if partial mortality of EAB populations occurs enough then ash may be able to resist the effects and survive with endemic levels of the beetle for extended periods of time. Cuddington et al. (2018) further explains that urban centers are more likely to not get the same benefits from temperature related mortality. A city such as Thunder Bay, Ontario may have problems with overwintering temperature mortality. The average low temperature in Thunder Bay is shown in Figure 6, with predicted and observed EAB mortalities shown in Figure 7. Thunder Bay typically receives a heavy snow accumulation that can cover several feet of the base of a tree. This insulating effect from the snow can increase the chance that EAB survive extreme cold events that Thunder Bay can experience. The average low for Thunder Bay in the winter months only reaches just under -20 degrees Celsius. The average observed mortality rates for EAB are roughly 20-30% for temperatures under -25 degrees Celsius. Thunder Bay does experience some extreme cold events but on average the winter is not cold enough to kill enough of the beetle population within the city.

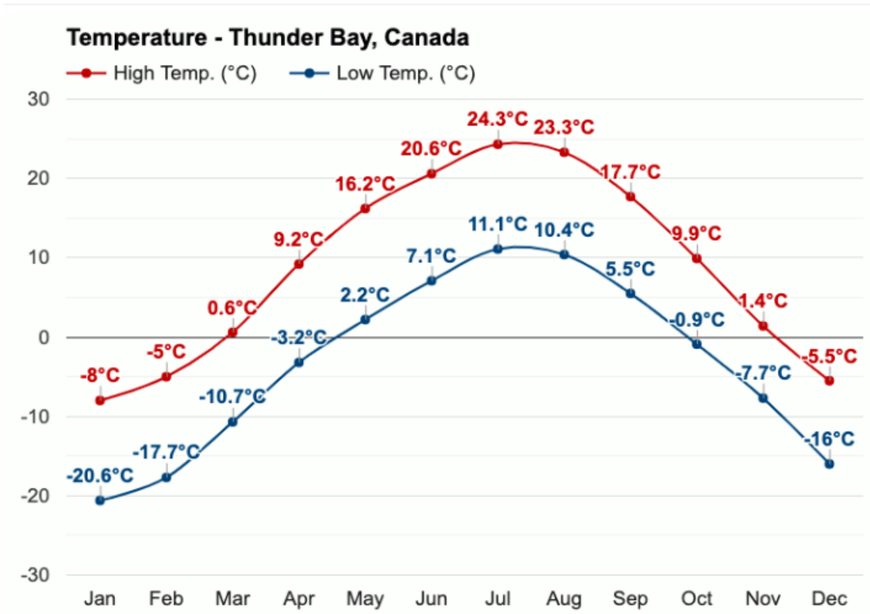

Figure 6. Monthly average temperature for Thunder Bay Ontario.

Source: weather-ca.com/thunderbay

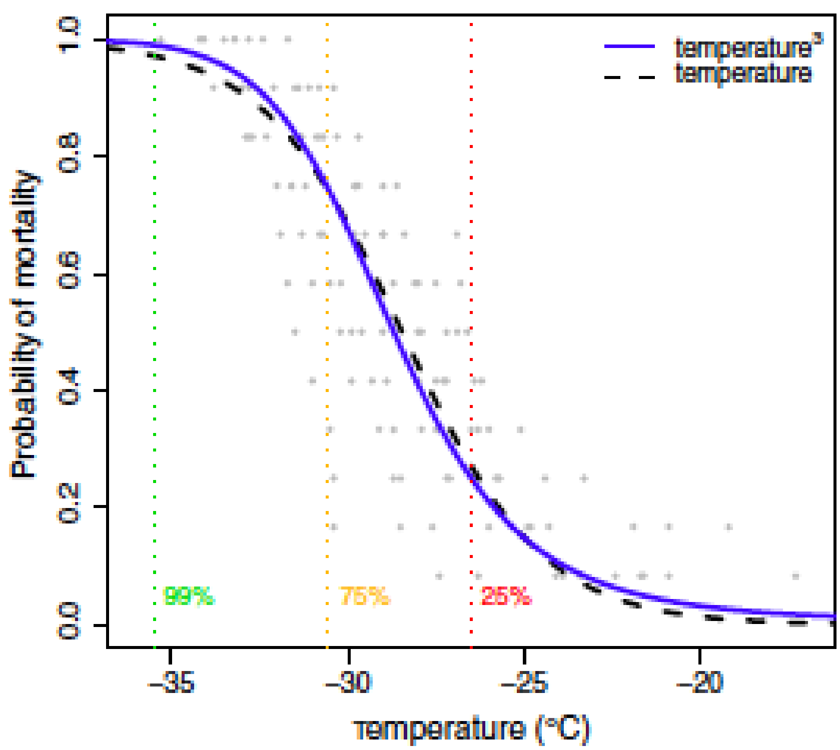

Figure 7. Temperature and predicted mortality. The grey dots represent measured mortality rates.

Source: Croswaithe et al. 2011

`

EAB MONITORING AND TREATMENT

It can be extremely difficult to detect an EAB outbreak for some years before more easily identifiable symptoms show (DeSantis et al. 2013). The 2016 Toronto Forest Threats manual outlines possible means of surveying for presence of EAB. These practices are monitoring for visual signs of the beetle, such as D-shaped exit holes, epicormic branching and crown dieback. Other monitoring methods include branch sampling for presence of the beetle, and determining presence of adult beetles using host volatiles and sticky traps.

A study by Poland and McCollough (2014) compared the effectiveness of four different trap types: green canopy traps, purple canopy traps, green double-decker traps and purple double-decker traps. Detection was 100% for both types of double decker traps, and were 82% and 64% for purple and green canopy traps, respectively. Overall, more beetles were captured in purple than green and in double-decker than canopy. Figure 8 shows the purple canopy trap available for use.

Figure 8. Purple canopy trap.

Source: APHIS.usda

Use this chart to compare common symptoms of Emerald Ash Borer infestation with other problems of ash trees.

SYMPTOM COMPARISON CHART

for Emerald Ash Borer infestation and other problems of ash trees

PROBLEMS	SYMPTOMS: Branch dieback	Thinning canopy	Epicormic sprouts	D-shaped exit holes	S-shaped larval galleries	Woodpecker damage
Emerald ash borer	X	X	X	X	X	X
Planted too deeply	X	X				
Trunk injury	X	X	X			
Poor site conditions	X	X	X			
Ash anthracnose		X				
Ash rust						
Verticillium wilt	X	X	X			
Ash decline	X	X				
Ash plant bug	X	X				
Ash sawfly		X				
Leafcurl ash aphid		X				
Ash flower gall mite		X				
Oystershell scale	X	X	X			
Ash/lilac borers	X	X				X
Eastern ash bark beetle	X	X				X
Flatheaded borers	X	X		X		X
Roundheaded borers	X	X	X			X

Figure 9. A comprehensive guide for common ash signs and symptoms.

Source: Iowa State University

Typically, the first visual sign of EAB is a thinning crown, but almost all other ash problems can also cause crown thinning, and this usually only occurs when the EAB infestation and population has increased. Figure 9 is an outline of the various symptoms that ash trees experience from a variety of different biotic and abiotic causal agents including fungi, nutrient deficiency and insects. Woodpecker damage and the D-shaped exit holes are some of the first signs of any infestation of EAB (Poland and McCollough 2014). But, because these signs are higher in the crown, they are difficult to see unless you are specifically looking for them. The option for treatment that does not appeal to most people is insecticides, but these are often the most reliable treatments, aside from complete removal of a tree. Removals are always an option for a city but the addition to city infrastructure that is removed with the tree can be devastating. Unfortunately, a tree is never just a tree and the added benefits of a tree are removed with it.

Insecticides

Figure 10. Treatment of a mature ash using TreeAzin systemic insecticide.

Source: Toronto's Forest Threats

Figure 11. An ash injected on private property in Thunder Bay.

Source: Thordarson 2019

Figures 10 and 11 above represent a typical treatment for EAB. This treatment method was developed by BioForest, a company based out of Sault St. Marie, Ontario. This product, commonly known as TreeAzin, is derived from the kernels of the neem tree, *Azadirachta indica* (Kreutzwizer et al. 2011). The active ingredient of TreeAzin for use against insects is Azadirachtin. This product is not to be confused with neem oil which is used for a variety of other purposes. I personally worked with the injection program for Rutter Urban Forestry in the city of Thunder Bay for private owners. The process of injection is simple; a hole is drilled into the lowest 30 cm of the trunk about 3.75 cm into the tree itself. From there, a small nozzle is inserted into the pre-drilled hole. A spring loaded cannister containing TreeAzin is mated to the nozzle and a small pin pierces the airlock, allowing the formula to be translocated into the tree with the help of the pressure from the spring. It can take anywhere from a few minutes to almost one hour for the canister to empty, depending on the ability of the tree to absorb the liquid into the vascular system of the tree. As a systemic insecticide the formulation is transported to all sections of the tree via the phloem. It takes an average of 48 hours for the solution to reach the outer extent of the foliage and branches of a tree, making it a fairly fast acting insecticide.

Figure 12. A typical bottle of TreeAzin systemic insecticide.

Source: Thordarson 2019

TreeAzin is commonly transported in 2 L bottles as shown above in Figure 12. To prepare for the injection you transfer the contents of a bottle or several bottles into a sealable cylinder that can then be pressurized. Figure 13 shows the system created by BioForest for filling cannisters. The system can be pressurized with air from any ordinary compressor. A cannister is attached to the ‘gun’ and liquid is sprayed into the small cannisters by pressing down on the trigger.

Figure 13. The full TreeAzin injection system setup with pressurized cylinder and cannisters.

Source: Thordarson 2019

Figure 14. An injection site wound in the bark and trunk after drilling.

Source: Thordarson 2019

Figure 14 is the wounding left in the trunk after the injection process is completed. According to BioForest, these wounds will typically callous over within 2 years-post injury. There are several reasons that TreeAzin one of the most commonly used licensed pesticides in Ontario for use against EAB. An article by Kreutzwizer et al. (2014) showed that 70% of leaf samples had no measurable concentration of Azadirachtin. This study further showed that there was no mortality among earth worms and no evidence was present that feeding rates of leaf litter were adversely affected. Based on the results of the study it was shown that foliar concentrations of treated ash posed little risk to terrestrial and aquatic microorganisms and decomposer insects (Kruetzwizer et al. 2010). Other insecticides in circulation such as Imidacloprid are licensed for use against EAB in Canada, but it is in the United States. Imidacloprid is a neonicotinoid insecticide under the trade name Ima-Jet. It is highly toxic to almost all species of insects and is especially deadly to bee populations making it a less frequently used insecticide in Canada.

Effectiveness of the TreeAzin product is based on two modes of action. Azadirachtin is an antifeedant and a growth inhibitor (McKenzie et al 2010). The larvae will be unable to feed and those that do feed will be unable to molt to the next larval instar and will die. Bioforest Technologies Inc. lists TreeAzin as a class four insecticide with a class 11 active ingredient. A class 4 pesticide is deemed to be less or least hazardous and can be used commercially under an exception to cosmetic pesticides ban, and a class 11 active ingredient means it can be used in biopesticicde formulations and low risk pesticide products (Government of Ontario 2014). Bioforest also has also performed unpublished research that indicates adult EAB females that feed upon ash leaf tissue with the formulation have lowered reproductive rates and eggs laid are not viable.

Another formulation in the testing phase is *Bacillus thuringiensis*, an entomopathogenic bacterium (Bauer et al. 2011). These insecticides have been used for over 50 years, with thousands of different strains that are very host specific. The research by Bauer et al. (2011) showed that *Bt* SDS-502 (the specific formula being used) was non-toxic to Lepidoptera and Hymenoptera species. A dose of 100 mg/ml of the solution caused a 50% mortality of the beetles, with death occurring within an average of four days.

Biological control

There are several options available to a municipality for biological control of EAB. A study by Bauer et al. (2008) looked at three new parasitoids, the parasitic wasps *Oobius agrili, Spathius agrili* (figure 15) and *Tetrastichus planipennisi*. *O. agrili* and *s. agrili* have both been released and established in several sites in Michigan. These insects are of the order Hymenoptera and are part of the families Encyrtidae, Braconidae and Eulophidae respectively.

Figure 15. *S. agrili female.*

Source: H-P Liu

These parasitoids will either lay eggs within the eggs of the EAB or inside the larval stage of the EAB resulting in death of the host. In Canada over 60,000 *T. planipennis* have been released at twelve sites in Ontario and Quebec. This species is able to attack up to 50% of EAB larvae, with 57 wasps produced per parasitized EAB larva (Canadian Forest Service). In 2015, testing began in Canada with *O. agrili*, with

25,000 specimens released at nine sites since then. *O. agrili* is an egg parasitoid that has a 60% parasitism rate in its native range (Canadian Forest Service 2017). Figure 16 is an example of the rearing process of *O. agrili*.

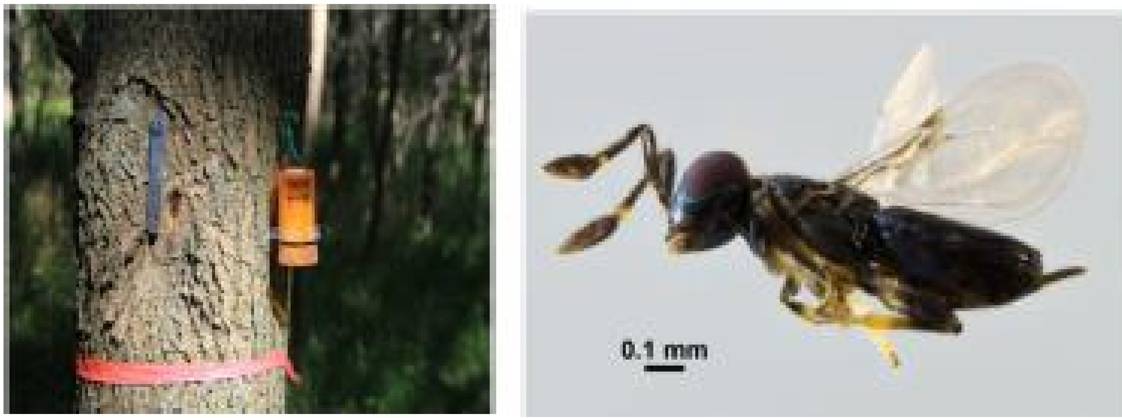

Figure 16. Container with EAB eggs and a specimen of *O. agrili* on the right.

Source: Canadian Forest Service.

These insects can sometimes cause a certain degree of worry among citizens, but all of these parasitic wasps are non-stinging insects and do not harm humans.

Quarantine zones

A cost-effective way to slow the spread of EAB and any other invasive species is to create quarantine zones around affected areas. Theses zones prohibit the movement of any and all firewood. This means that no wood from any species of tree is allowed to be transported outside of the city. Thunder Bay is currently a quarantine zone to mitigate the movement of EAB-infested firewood to other areas. These quarantines only work if people adhere to them, and after EAB was discovered in Thunder Bay in 2016, it was found in Winnipeg only one year later. An 800 km distance is impossible for the beetle to travel on its own. These quarantine zones are helpful to create public awareness but must be enforced to ensure success.

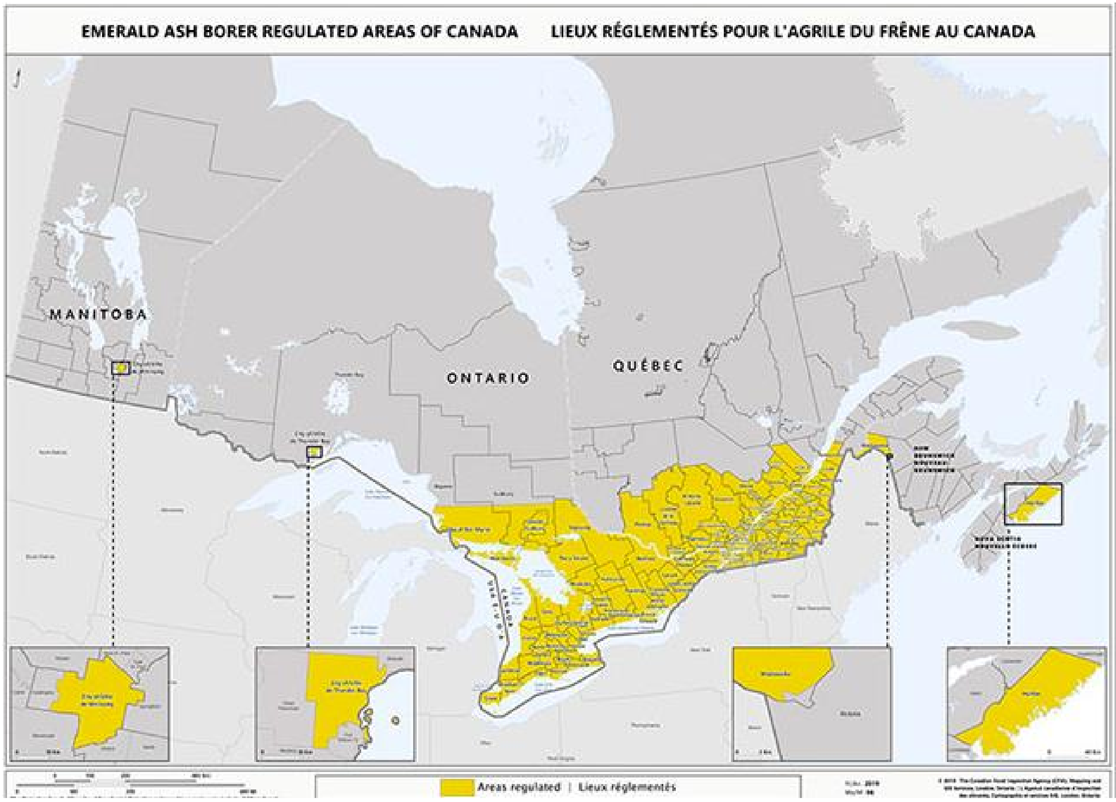

Figure 17. CFIA regulated areas for EAB.

Source: CFIA website

The current areas under regulation are shown above in figure 17. The areas of concern are mainly contained to Southern Ontario and Southern Quebec. Quarantine zones rely on the participation of citizens; any firewood of the affected tree species must not be removed from the specified zone.

MATERIALS AND METHODS

Information regarding the Thunder Bay integrated pest management plan was obtained. The city of Thunder Bay as well as Rutter Urban forestry were contacted to obtain city wide and private work to control EAB and other insects.

Information was acquired from Thunder Bay pertaining to population numbers over the course of the current infestation as well as the total number of ash trees in the city and those that are being treated, removed or left alone. Data was also obtained from several other cities including Toronto and Winnipeg for comparison purposes.

RESULTS

THUNDER BAY

Table 1. Thunder Bay EAB yearly program summary

Year	Injections	Removals	Total planted
2016	20	16	155
2017	842	42	263
2018	831	146	830
2019	657	150	1000

Source: Robert Scott 2019

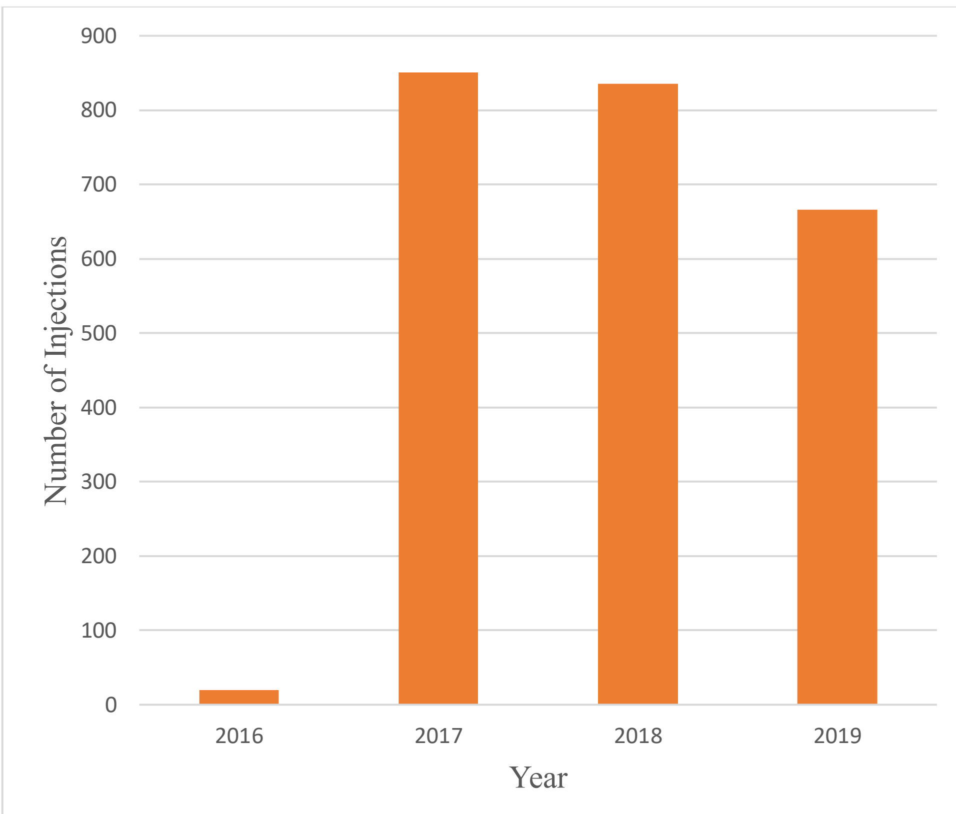

Figure 18. Yearly EAB treatment numbers for Thunder Bay

Source: Robert Scott 2019

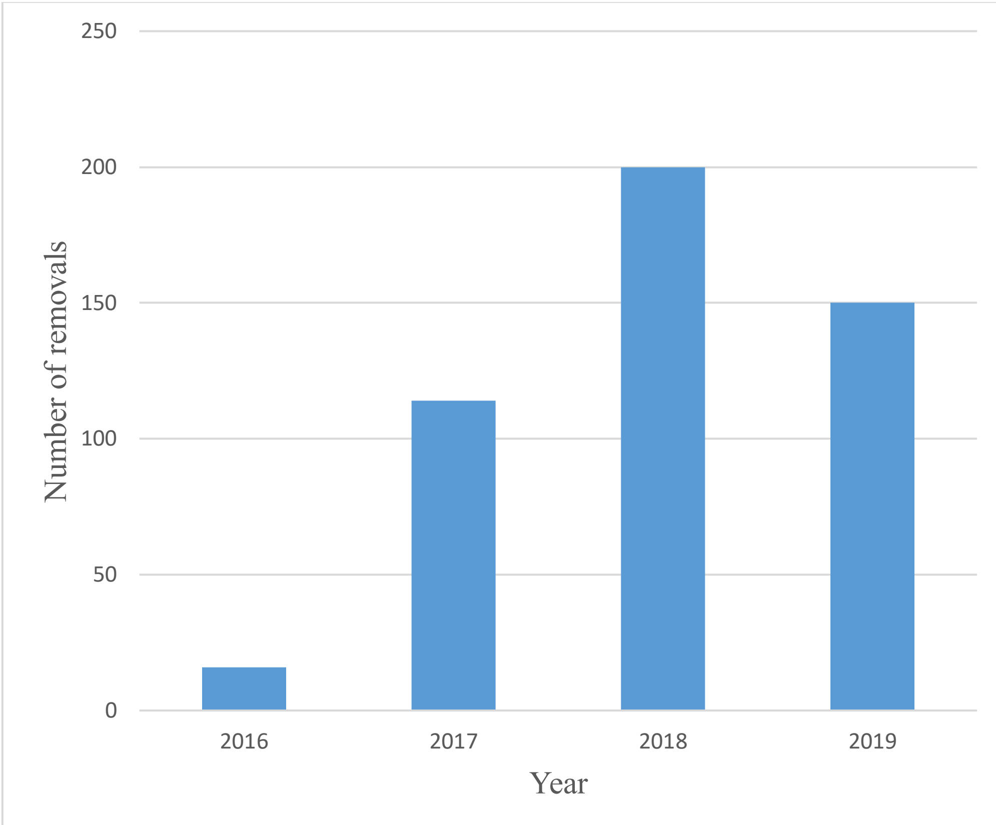

Figure 19. Yearly removals for ash in Thunder Bay

Source: Robert Scott 2019

With an infusion of funds in 2017 the city was able to perform exponentially more injections than previously with removals also increasing and the ability to replace and plant more trees becoming more of a priority. Total trees planted have increased yearly and is projected to continue increasing over the next several years. Over the next ten years there may be a decrease in the total number of yearly injections as most ash trees will be part of a biannual treatment program and others will have continued to be removed.

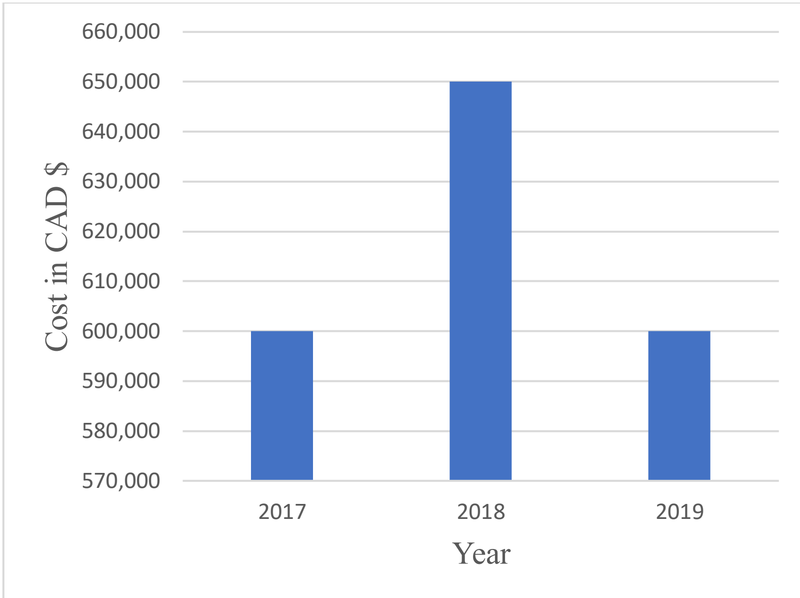

Figure 20. Total yearly spending for EAB program with all costs included

Source: Robert Scott 2019

Table 2. Yearly EAB trap data for Thunder Bay

Year	Number of traps	Samples found
2016	115	26
2017	22[1]	17
2018	100*	16**
2019	54	10

Source: Robert Scott 2019

*100 traps within the city of Thunder Bay and 22 more in surrounding districts
**16 traps contained insects for a total of 25 insects found.
[1] Trap data for 2017 comes from Rutter Urban Forestry

The number of EAB beetles found in traps has decreased since 2016 from 26 to 10 suggesting that the treatment program and removals of ash trees throughout the city, along with several extreme low winter temperatures has been successful at mitigating the growth of the insect population.

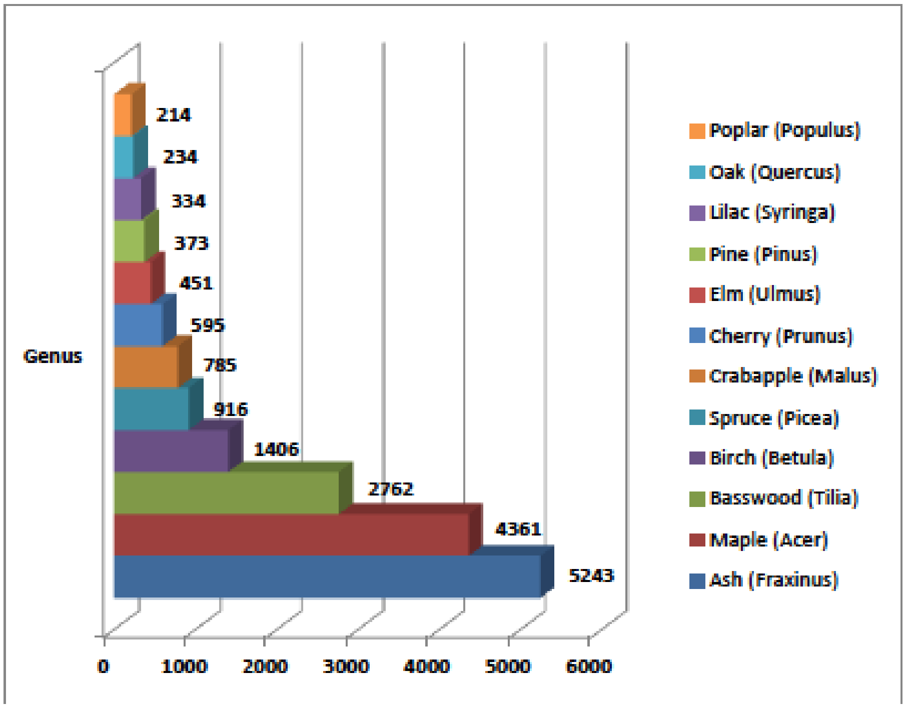

Figure 21. A 2011 percent distribution by genus for Thunder Bay

Source: Davey Resource Group 2011

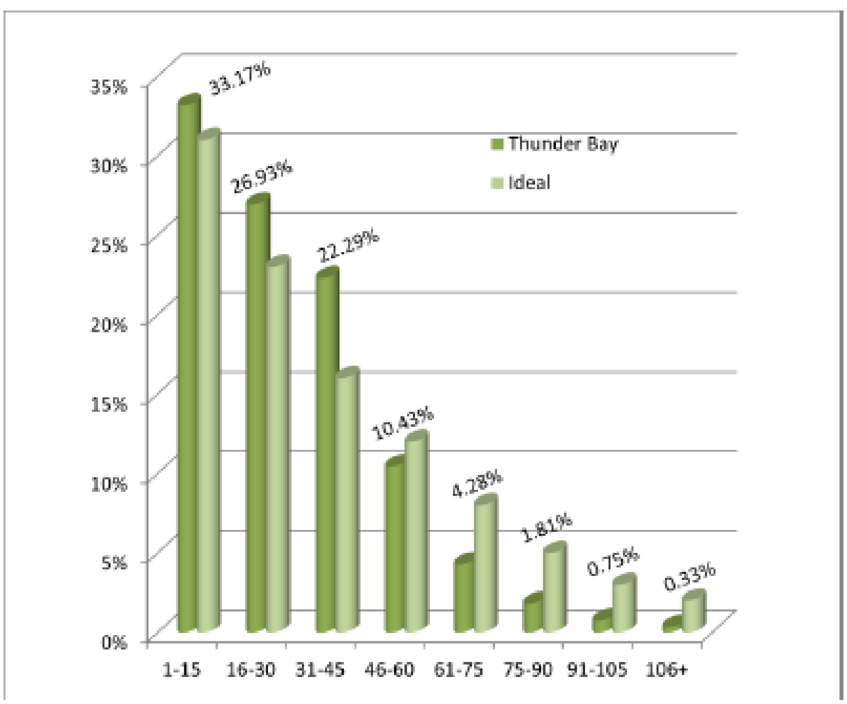

Figure 22. Size class distribution in 2011 compared to ideal

Source: Davey Resource Group 2011

The 2011 city management plan for forestry showed a large number of ash dominating the inventory of the street trees meaning a significant portion was at risk of the beetle. The management plan also showed an age class distribution that heavily favoured very young trees with 82% of all trees under 45 years old.

OTHER MAJOR CITIES BEING AFFECTED

Table 3. Percent composition of ash for 3 Canadian cities

	Thunder Bay	Toronto	Winnipeg
Ash	6700	860000	101000
Total	31000	1200000	280000
Percent	22	72	36

Source: Various informants 2019

Comparatively the city of Thunder Bay has a very low percentage cover of ash compared to Toronto at 72% ash and is also below Winnipeg that has a 36% cover of ash. However, it also has a significantly lower total number of trees.

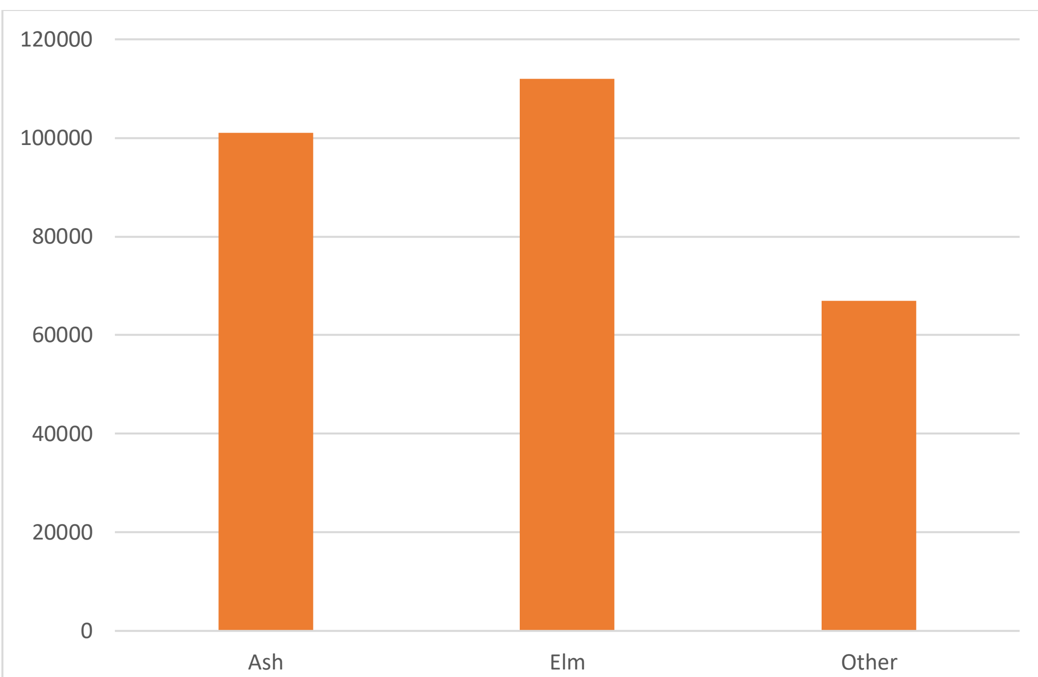

Figure 23. Street tree composition for Winnipeg Manitoba

Source: Dr. Leonard Hutchison 2019

Table 4. Removals for Winnipeg following introduction of EAB in 2017

Year	Injections	Removals
2017	~100	~100
2018	1000	800

Source: City of Winnipeg 2018

The city of Winnipeg has a massive component of ash but only 1000 injections and 800 removals. The removal number is larger by more than 600 trees, but the number of injections is much closer. Considering the number of ash trees in the inventory Thunder Bay has done an excellent job with a much lower annual budget with only $6 million over ten years for Thunder Bay starting in 2017.

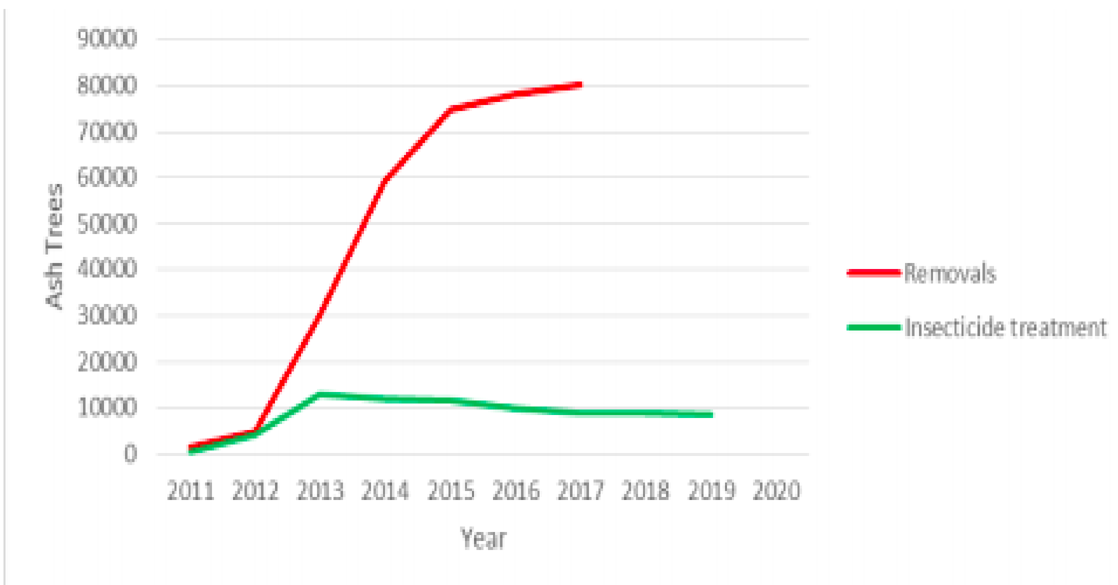

Figure 24. Ash tree removals and treatments for the City of Toronto with projections for 2017-2020.

Source: Toronto's Forest Threats 2016

Table 5. Trap number for the City of Toronto

Year	Average count in traps	Number of traps
2016	7	93
2017	12	93
2018	3	93
2019	33	93

Source: City of Toronto correspondent 2019

Toronto has been at the forefront of the EAB infestation since 2012 and has steadily treated nearly 10,000 trees yearly and increasingly removed trees over 2012-2017. Of the 860,000 ash trees in Toronto in 2016 nearly 220,000 had already been removed. Toronto has successfully treated its trees and is continuing to treat until the threat of EAB has left the city. The number of beetles found have been cyclical with the average number of beetles found in a trap in 2019 at an all-time high of 33. This is concerning considering the previous year has an average number of beetles per trap at only three.

DISCUSSION

The current situation with EAB in Thunder Bay is not as dire as other places in Ontario. The City of Thunder Bay organized a management plan to combat the emergence of EAB after the 2016 summer season. A budget of approximately six million dollars allocated over 10 years for urban forestry was approved in 2016 (City of Thunder Bay). This large budget increase was in response to the finding and identification that EAB was, in fact, within the city. According to Robert Scott, a city employee and EAB management intern, preparation for the arrival of EAB began in 2012. It took 14 years for the beetle to spread from Windsor, the most southern point of

Canada, to Thunder Bay. The route of introduction is not clear, but it may have been introduced from across the border from Minnesota or travelled on packaging from southern areas of the province.

The ash population in Thunder Bay accounts for upwards of 25% of all municipal street trees, not including those on privately owned property. Described as one of the ugliest cities in Canada because its lack of green space, losing 25% of the canopy to EAB-induced mortality would be a severe blow to an already sparse urban tree population. With a yearly budget of $600,000 it is extremely difficult to ensure all aspects of forestry are taken care of. Treatment costs for 2017-2019 were $161,000, $175,000, and $150,000, respectively. Those costs are for treatment alone and does not include removal and replacement costs, as well as all other urban forestry operations that the city needs to perform. Thus, while the ash population in Thunder Bay is not nearly as high as the 76% that Toronto boasts, the yearly budget is miniscule and is almost insufficient to deal with the current capacity of work. Thunder Bay is a pinch point for travelling east or west through Canada on the Trans-Canada highway. Thunder Bay is also a major shipping port on the Great Lakes and, due to both of these facts, it is can be a hub for the transport of invasive species. The ability to slow and, hopefully, stop the spread of EAB can potentially save thousands of naturally growing ash trees. Stopping spread of EAB would ensure the survival of our native ash tree species. Thunder Bay currently relies on cold winters to help slow the spread of EAB, but if cold snaps occur with lower frequency EAB will no longer experience such high mortality.

A natural and cultural Canadian landmark is located just outside the City of Thunder Bay. The Fort William Historical Park has a large forest of ash and elm trees surrounding it. Currently, the park has no action plan to combat EAB, and it is outside of the Thunder Bay quarantine zone. The loss of natural forests is devastating to ecosystems than the loss of urban trees. However, management of urban tree populations for invasive species is key to the protection of forests outside of cities. Unfortunately, one year after its identification in Thunder Bay, EAB was found in Winnipeg, Manitoba - a distance of over 800 km. This distance would be impossible for the beetle to travel on its own and it was almost certainly introduced to Winnipeg on EAB-infested firewood.

Thunder Bay is currently doing an excellent job at keeping the population of EAB under control. Populations have not yet reached epidemic levels and we are able to maintain ash trees within the city. Windsor, Ontario was the first point of incidence in Canada and, according to Paul Giroux, the city forest manager of Windsor, EAB has ‘come and gone’. The beetle has effectively removed 99% of all ash within the city and can no longer persist without its food source. According to a tree inventory in 2019 there were <500 ash trees found throughout the city of Windsor. These ash trees may have been removed enough from the bulk of the population to survive the entrance and ‘exit’ of the beetle in 2012-2013. The beetles have moved on and there are some survivors among the ash population.

Can we save ash? Will it be possible to maintain ash in perpetuity or at least reestablish after the beetle has been taken care of? A Carolinian species of ash, the blue ash, has shown resistance to EAB (Hutchison, pers. comm.). However, this species is unable to overwinter in the extreme cold in much of central and northern Canada. Paul Giroux also made comment about a twenty-acre patch of pumpkin ash that he owns. The beetles are present within his small 6-8 foot tall forest but the trees appear to currently be coexisting with EAB or at least maintaining enough vigor to survive for now. We also need to look at how other insects of the *Agrilus* genus have reached a balance in our forests as an endemic pest like the bronze birch borer (Rutter 2020).

The Emerald ash borer problem has brought attention to urban trees and currently over 100% of removed ash trees in Thunder Bay are being replaced with other tree species. As a result, the forests in urban areas is being replenished slowly. Shelly Vescio, the former city forester for the City of Thunder Bay, felt that the city has managed for EAB as well as can be expected with a limited budget and unexpected arrival of EAB in 2016. Her main concern was not about EAB but rather gypsy moth. She felt that the introduction of EAB was a kick starter for proper planning to mitigate the effects of other invasive species.

Public awareness is essential for the proper management of EAB in Thunder Bay. No matter how many yearly treatments the city performs, it will be all for naught if private landowners do not also treat their ash trees. Currently, only one company provides such treatment service within Thunder Bay, Rutter Urban Forestry. When working for them in 2019 I performed 50-75 treatments. This is not nearly enough people wanting to save their ash trees. A single ash tree can be infested by hundreds of beetles and a street that is treated for the beetle on a biannual basis is not safe if private trees are infested. People are wary of spending limited financial resources on the necessary treatment options for these trees.

Protocols must be followed and enforced to ensure survival of ash trees in natural areas. Urban trees are a huge asset to the landscape and are shown to even improve the value of a home. Loss of canopy is a detriment, but it is not just about the cities. Cities and suburbs are a barrier to the surrounding woodlands and natural ecosystems. As a riparian tree, the ash is a key factor in the control of river side erosion as well as critical habitat in and around a watercourse. The city is the first line of defense after an invasive species like EAB has been introduced and allowed to proliferate. The effective treatment and removal of ash trees as seen in Thunder Bay has shown that EAB can be kept in check while still preserving the urban tree canopy. Thunder Bay is an example of how to properly manage for EAB. Despite a low budget and few staff, Thunder Bay has created a successful quarantine area that has slowed the spread of the beetle to outside of the city. The introduction of the beetle to Winnipeg was an unfortunate incident that likely occurred when firewood containing EAB was transported from an EAB-infested area. Compared to other cities with much higher budgets like Toronto and Winnipeg, Thunder Bay has done equivalent work in the areas of treatment and removal. With only 6700 ash trees it is a considerably lower number than even Winnipeg, but this makes up the largest single species portion of the cities inventory. Thunder Bay only has a population of approximately 110,000 compared to Winnipeg's 750,000 and Toronto's 2.93 million meaning it will have a much lower city budget for costs associated with invasive pests like EAB. Thunder Bay has set out more traps than Toronto and beetle numbers have decreased yearly compared to the increase of Toronto's populations. The number of trees in the city has a direct response to the ferocity of the epidemic. Less available food in Thunder Bay coupled with proper treatment plans has allowed us to be competitive in our management of EAB.

CONCLUSION

EAB has spread throughout Ontario and has reached Quebec and Manitoba. Although ash is not considered a valuable tree from a commercial forestry perspective it is nevertheless an essential part of many urban forests. It makes up more than 25% of the canopy cover in Thunder Bay, 76% of the canopy in Toronto, and there are 350,000 ash trees throughout the streets, parks, and private properties of Winnipeg.

Thunder Bay is doing an excellent job maintaining low EAB populations and keeping its ash trees alive. Research has shown that the lower winter temperatures near Thunder Bay have been key to the success, but a changing climate means insufficiently cold temperatures may not occur with enough frequency to keep EAB populations in check over the long-term. Climate change is also a risk factor for the establishment of other invasive insects that would not typically survive in colder climates. The current two-year life cycle of EAB could become a one-year life cyle if temperatures continue to rise globally. The shortened life cycle may result in a change in infestation levels and further impact the likelihood of maintaining an ash population in the city and surrounding areas. A solid management strategy for current invasive insect problems increases likelihood of being able to achieve the desired results in later invasive pest situations.

LITERATURE CITED

Bauer, L.S., Haack, R.A., Miller, D.L., Petrice, T.R., and Liu, H. 2003. Emerald Ash Borer Life Cycle. Research and Technology Development Meeting.

Bauer, L.S., Liu, H., Miller, D., and Gould, J. 2008. Developing a Classical Biological Control Program for Agrilus planipennis (Coleoptera: Buprestidae), an Invasive Ash Pest in North America. Newsletter of the Michigan Entomological Society V53 (3&4).

Bauer, L.S., Miller, D.l., Londono, D. 2011. Laboratory Bioassay of Emerald Ash Borer Adults with a *Bacillus Thuringiensis* Formulation Sprayed on Ash Leaves. Emerald Ash Borer National Research and Technology Development Meeting pp. 131-133.

Bioforest Technologies Inc. TreeAzin Systemic Insecticide. http://www.bioforest.ca/index.cfm?fuseaction=content&menuid=12&pageid=1012

Boardman A.E., D.H. Greenberg, A.R. Vining, and D.L. Weimer. 2001. Cost-benefit analysis: Concepts and practice. Prentice Hall: Upper Saddle River, New Jersey. 526 pp.

Canadian Forest Service. 2017. Release of parasitic wasps for biological control of emerald ash borer in Canada. Natural Resources Canada. ISSN 1496-7847

Crosthwaite, J.C., Sobek, S., Lyons D.B., Bernards, M.A., and Sinclair B.J. 2011. The overwintering physiology of the emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera:Buprestidae). Journal of Insect Physiology 57:166–173.

Cuddington, K., Sobek-Swant, S., Crosthwaite, J.C., Lyons, D.B., and Sinclair, B.J. 2018. Probability of emerald ash borer impact for Canadian cities and North America: a mechanistic model. Biology Invasions. 20:2661–2677

de Groot, P., Biggs, W.D., Lyons, D.B., Scarr, T., Czerwinksi, E., Evans, H.J., Ingram, W., and Marchant, K. 2006. A Visual Guide to Detecting Emerald Ash Borer Damage. Natural Resources Canada. Ontario Ministry of Natural Resources. 20p.

DeSantis, R.D., Moser, W.K., Gormanson, D.D., Bartlett, M.G., and Vermunt, B. 2013. Effects of climate on emerald ash borer mortality and the potential for ash survival in North America. Agricultural and Forest Meteorology 178-179: 120-128.

Federal Register. 2003. Emerald ash borer, quarantine and regulations. 7 CFR Part 301, 68(198): 59082–59091.

Gould, J., Tanner, J., Winograd, D., and S. Lane. 2005. Initial studies on the laboratory rearing of emerald ash borer and foreign exploration for natural enemies. P. 73–74 in Emerald ash borer research and technology development meeting, Mastro, V., and R. Reardon (comps.). FHTET-2004–15, USDA Forestry Service, Morgantown, WV.

Government of Ontario. 2014. Classification of Pesticides. Class 4.

Herms, D.A., McCullough, D.G. 2014. Emerald Ash Borer Invasion of North America: History, Biology, Ecology, Impacts, and Management. Annual Review of Entomology 59:13-30.

Klooster. W.S., Herms, D.A., Knight, K.S., Herms, C.P., McCollough, D.G., Smith, A., Gandhi, K.J.K., Cardina, J. 2012. Ash (*Fraxinus* spp.) mortality, regeneration, and seed bank dynamics in mixed hardwood forests following invasion by emerald ash borer (*Agrilus planipennis*). Biologal Invasions 16: 859-873.

Kreutzwizer, D., Thompson, D., Grimalt, S., Chartrand, D., Good, K., and Scarr, T. 2011. Environmental safety to decomposer invertebrates of azadirachtin (neem) as a systemic insecticide in trees to control emerald as borer. Journal of Ecotoxicology and Environmental Safety 74: 1734-1741.

Krutilla, J. 1967. Conservation Reconsidered. The American Economic Review 57: 777–786.

Liu, H., L.S. Bauer, R. Gao, T. Zhao, T.R. Petrice, and R.A. Haack. 2003. Exploratory survey for the emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), and its natural enemies in China. Great Lakes Entomology 36: 191–204.

Lyons, D.B., Jones, G.C., and Wainio-Keizer, K. 2004. The biology and phenology of the emerald ash borer. *Agrilus planipennis,* P. 5 *In* Emerald ash borer research and technology development meeting, Mastro, V. and R. Reardon. (comps.). FHTET-2004-02, USDA Forestry Service, Morgantown, WV.

McKenney, D.W., Pedlar, H.J., Yemshanov, D., Lyons, D.B., Campbell, K.L., and Lawrence, K. 2012. Estimates of the Potential Cost of Emerald Ash Borer (*Agrilus planipennis* Fairmaire) in Canadian Municipalities. Arboriculture and Urban Forestry 38: 81-91.

McKenney, D.W., Pedlar, J.H. 2012. To Treat or Remove: An Economic Model to Assist in Deciding the Fate of Ash Trees Threatened by Emerald Ash Borer. Arboriculture and Urban Forestry 38: 121-129.

McKenzie, N., Helson, B., Thompson, D., Otis, G., McFarlane, J., Buscarini, T., and Meating, J. 2010. Azadirachtin: An Effective Systemic Insecticide for Control of *Agrilus planipennis* (Coleoptera: Buprestidae). J. Econ. Entomology 103: 708-717.

Parks, Forestry and Recreation. 2017. Toronto's Forest Health Threats. City of Toronto. 61p.

Poland, T.M. and McCollough, D.G. 2014. Comparison of Trap Types and Colors for Capturing Emerald Ash Borer Adults at Different Population Densities. Environmental Entomology 43: 157-170.

Poland, T.M. and McCullough, D.G. 2006. Emerald Ash Borer: Invasion of the Urban Forest and the Threat to North America's Ash Resource. Journal of Forestry 118-124.

Rutter, Vince. 2020.

Ryall, K. 2017. Release of parasitic wasps for biological control of the emerald ash borer in Canada. Natural Resources Canada, Canadian Forest Service. Front Line Express 82. 2p.

Tussey, D.A., Aukema, B.H., Charvoz, A.M., Venette, R.C. 2018. Effects of Adult Feeding and Overwintering Conditions on Energy Reserves and Flight Performance of Emerald Ash Borer (Coleoptera: Buprestidae). Environmental Entomology 47: 755-783.

Venette, R.C., and Abrahamson, M. 2010. Cold hardiness of emerald ash borer, *Agrilus planipennis*: a new perspective. In: Black ash symposium: proceedings of the meeting; 2010 May 25-27;. Bemidji, MN. Cass Lake, MN: U.S. Department of Agriculture, Forest Service, Chippewa National Forest. 5 p.